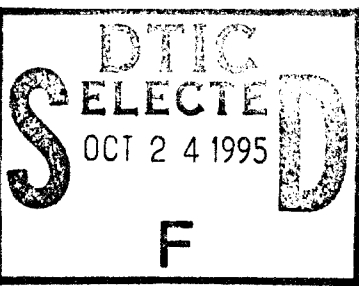19951019 184

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CHANGES IN THE THRESHOLDS OF GAS FLOW BETA COUNTERS

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INTRODUCTION

Many laboratories need a reliable counter for low-energy beta particles. In an effort to fill this need some counters have been tried through which helium flowed slightly above atmospheric pressure.

BUBBLER

HELIUM TANK

COUNTER

NEHER-HARPER CIRCUIT
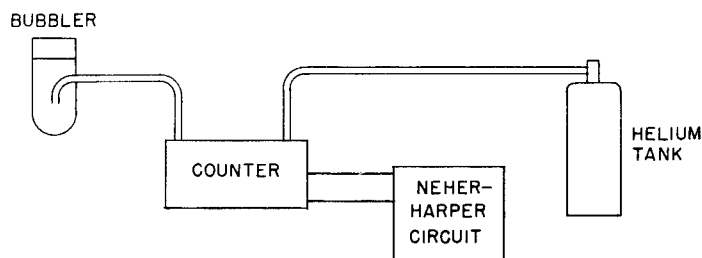
One advantage of such a flow counter is that a thin window has to withstand only a small pressure difference. Another is that placing an active sample inside the counter is simpler.

The counters used by the writer operated on a Neher-Harper circuit and in the Geiger-counter region. The results show that the threshold and other characteristics of such a flow counter can change with the flow rate. Apparently the threshold changes with the flow rate because the composition of the gas in the counter changes with the flow rate. The composition changes with the flow rate if air diffuses through leaks into the counter against the higher internal pressure, or if the thin window on the counter is porous.

THE "BACK DIFFUSION" OF AIR

The first counter tried, and several others as well, had no window and leaked. At first it was believed that the higher pressure inside the counter would keep out the air even if there were leaks. Later it was found that the thresholds of leaking counters change with the flow rate. Figure 1 shows one set of data. Rather inaccurately,

$$T - T' = k/R$$

in which T is the threshold of the counter, R is the flow rate, and T' and k are constants. Reducing the leak tends to reduce the variation with flow rate. Table 1, as well as some experiments with methane flow counters,[2] illustrates this. The "leak rate" is the rate at which helium leaked out when the pressure was a millimeter of mercury above atmospheric. The usual way of measuring the leak rate was to stop the flow of helium and observe the level of the liquid in the outlet tube A of the bubbler as the level rose with time
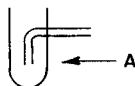
A

Table 1.

Experiment	Remarks on apparatus	Leak rate (cc/min)	k (volt-cc/min)
A	Brass counter, 98% He, rubber tubing	0.3	350
B	Brass counter, 98% He, rubber tubing	0.1	570
C	Glass counter, 98% He, rubber tubing	0.01	80
D	Glass and metal system, 98% He	0.005	10
E	Glass and metal system, 98% He	0.0001	2

For more accurate results the temperature and barometric pressure were taken into account. To detect the smallest leaks the system was evacuated. A gas can diffuse through a porous solid into a region of higher total pressure, and a small leak may resemble a "pore" of a solid. There is, then, some reason to believe that air can diffuse into the counter through leaks even when the total internal pressure exceeds the external pressure.

Let us use the following symbols:

T = threshold potential of counter under given conditions

T' = limit approached by T as flow rate increases

M = volume of air entering system in unit time

R = volume of gas leaving system through bubbler in unit time

y = partial pressure of air added to helium

t = time since beginning of experiment

V = volume of system

Let us make the following assumptions:

1. $T - T' = by$, where b is a constant

2. M is a constant in any one apparatus

3. The gas inside the counter is everywhere the same in composition

4. R is much larger than M

The rate at which air enters the system is M; and the rate at which it leaves is Ry. The rate at which air accumulates is V(dy/dt) or (M-Ry). Therefore,

$$V \frac{dy}{dt} = M - Ry. \tag{1}$$

The solutions of the equation are as follows:

Case I: $R = O$

$$\frac{dy}{dt} = \frac{M}{V} \tag{2}$$

$$\frac{dT}{dt} = \frac{bM}{V}$$

Case II: R = constant other than zero

$$y = Pe^{-(R/v)t} + M/R, \text{ P being a constant of integration}$$

$$\tag{3}$$

$$T-T' = We^{-(R/v)t} + bM/R, \text{ W being a constant of integration}$$

In the steady state, then,

$$T-T' = bM/R \tag{4}$$

We have already seen (Figure 1) that, just as equation 4 requires, (T-T') is nearly inversely proportional to R. The constant bM is the same as the constant k, which was used before. After the flow has stopped, according to equation 2, the threshold should rise with time at a constant rate. Figure 2a and 2b confirm this. Equations 2 and 4 give two independent methods for evaluating the constant bM. Table 2 illustrates how well the two methods agree in practice.

Table 2.

Remarks on apparatus	bM in volt-cc/min by equation 2	bM in volt-cc/min by equation 4
Brass counter, rubber tubing	270	300
Brass counter, rubber tubing	700	570
Silvered-glass counter, rubber tubing	28	79

Evidence for the exponential term in equation 3 appears in Figure 2b.

A few sealed counter tubes have been made containing known mixtures of helium and air, or helium and water vapor. Figures 3a and 3b show the threshold as a function of the partial pressure of the air when the total pressure was 28 centimeters. As we assumed, T is roughly a linear* function of y, with dT/dy = 38,000 volts/atm. If the same is true at a total pressure of one atmosphere, then b = 38,000 volts/atm. Moreover, the threshold of a copper counter[20] 6'' long, 1 5/8 inches in diameter, and with a 0.004 inch center wire is 580 volts with 99.9% helium and 1,100 volts with 98% helium. The 98% helium was 1.5% nitrogen.[16] Hence 0.015 atm of nitrogen raises the threshold by 520 volts, and b = 35,000 volts/atm. The values of M obtained from bM and b are not unreasonably large.

The preceding section has presented data to show how the threshold depends on the flow rate, the size of the leak, and the time. The various effects are explained on the assumptions that air can diffuse into the counter through leaks, and that T-T' is proportional to the partial pressure of the air in the counter.

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*In a limited region. The threshold of a G-M counter filled with air at atmospheric pressure lies[3] between 4,000 and 5,000 volts.
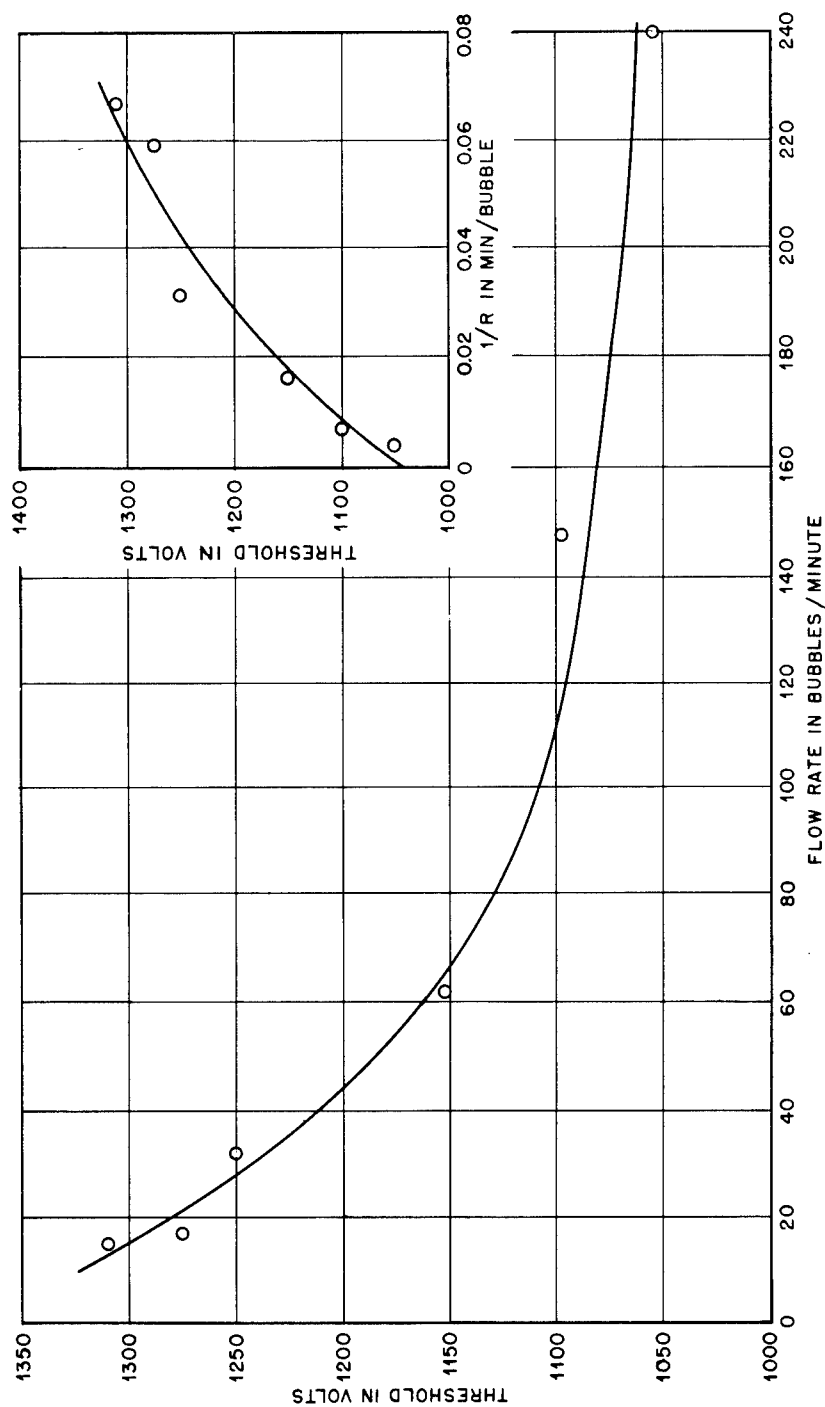
Figure 1. Threshold as function of flow rate. Brass flow counter; 98% helium, rubber tubing. Leak rate~0.3 cc/min.
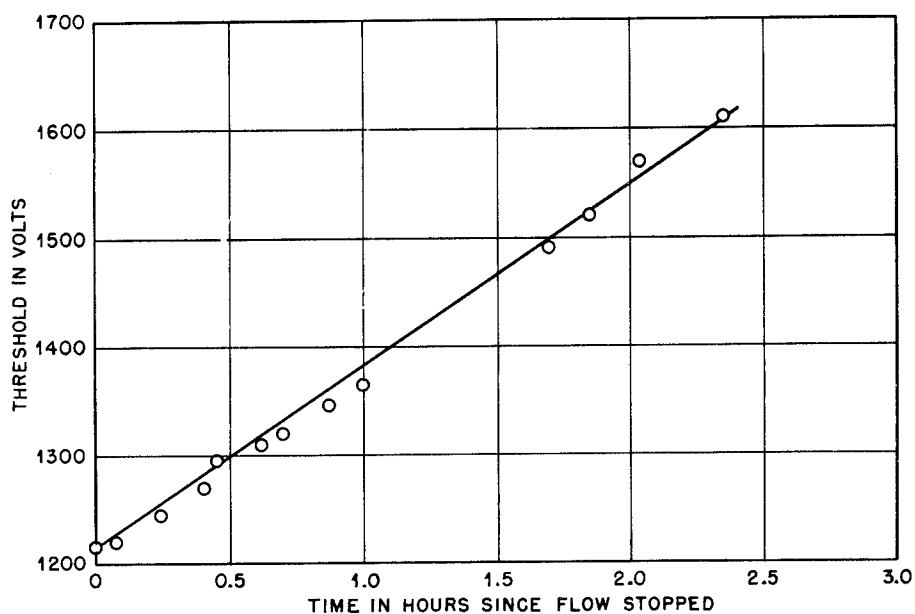
Figure 2a. How threshold varied with time while helium flow stopped. Brass flow counter; 98% helium, rubber tubing. Leak rate 0.1 cc/min.
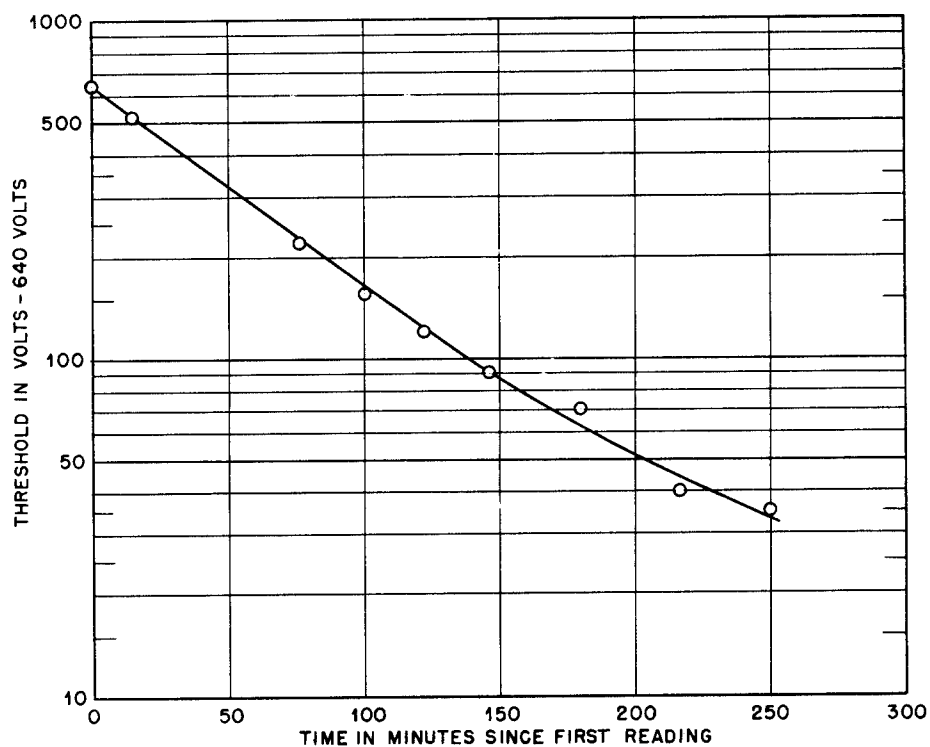

Figure 2b. How threshold varied with time while helium replaced air. Copper counter with Nylon window; flow system of glass and metal. 99.9% helium. At first the system was full of air. Next a certain volume of helium was allowed to flow through the system. The flow rate was then set at thirty bubbles/minute and the readings shown on this graph began.

Relation observed: $T - 640 = 640e^{-0.013t}$ Relation predicted: $T - 640 = 640e^{-0.018t}$
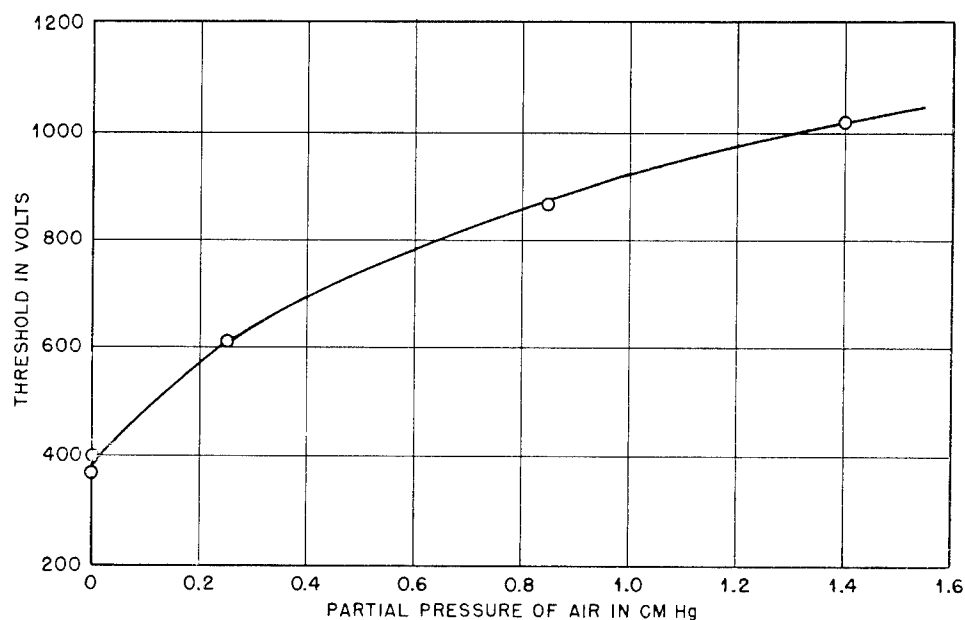
Figure 3a. Threshold of counters containing helium and air. b = 38,000 volts/atm. Data was obtained with Eck and Krebs silvered-glass counter tubes, whose cathodes are 10 cm long and 1.9 cm in diameter, and whose center wires are 0.01 cm in diameter. The total pressure was 28 cm Hg.

Figure 3b. Threshold of counters containing helium and water vapor. e = 38,000 volts/atm. Data was obtained with Eck and Krebs silvered-glass counter tubes, whose cathodes are 10 cm long and 1.9 cm in diameter, and whose center wires are 0.01 cm in diameter. The total pressure was 28 cm Hg.
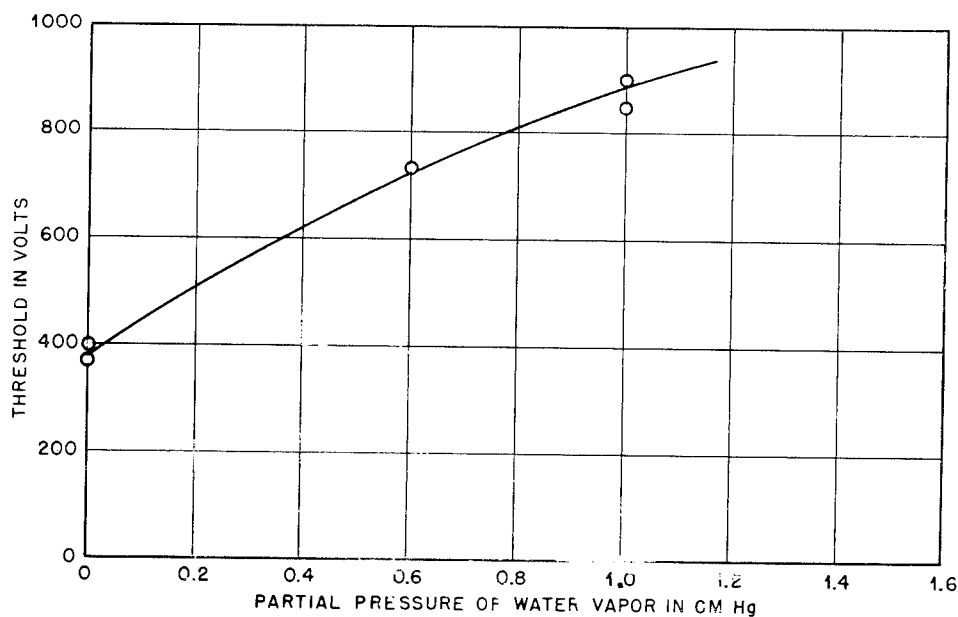
THE PERMEABILITY OF WINDOWS TO WATER VAPOR

One flow system with a Nylon window was thought to have no leaks of significant size. Nevertheless the threshold of the counter, when 99.9% helium was used, varied between 600 volts and 1,100 volts. The explanation apparently is that Nylon transmits water vapor.*

Let us introduce the following additional symbols:

   m = volume of water vapor entering the system in unit time (reduced to standard conditions)

   z = partial pressure of water vapor inside the system

   z_0 = partial pressure of water vapor outside the system

Let us make the following assumptions:

$$T-T' = cx, \text{ c being a constant} \tag{5}$$

$$m = h(z_0-z), \text{ h being a constant for a given window} \tag{6}$$

The gas in the system is everywhere the same in composition. As before, the rate of accumulation of water vapor inside the system equals $V\, dz/dt$ and m-Rz. Therefore,

$$V\frac{dz}{dt} = hz_0-hz-Ry \tag{7}$$

$$\frac{dz}{dt} + \frac{h+R}{V}\, z = \frac{hz_0}{V} \tag{8}$$

The solution of this differential equation is

$$z = Qe^{-(h-R/v)\, t} - \frac{h\, z_0}{h+R}$$

in which Q is a constant of integration. Therefore,

$$T-T' = Xe^{-(h+R/v)\, t} + \frac{c\, hz_0}{h+R}, \tag{9}$$

in which x is a constant of integration. In the steady state,

$$T-T' = \frac{c\, hz_0}{h+R} \tag{10}$$

The constants in equation 10 may be evaluated — c from experiments with sealed counters (See Figure 3), h from measurements of the permeability of Nylon to water vapor (Table 3), z_0 from measurements of the temperature and relative humidity, and T′ from experiments with the flow counter. Figure 4 shows a calculated curve and some experimental points for counters with Nylon and Saran windows. A test was made with a cup of anhydrous calcium chloride over the window. The results, also plotted in Figure 4, confirm that the humidity outside the window affects the counter.

A few experiments dealt with the threshold as a function of time (Figure 5). In one of these experiments the counter was evacuated and filled with helium, and the helium was allowed to flow through the counter with the window exposed to the atmosphere. The threshold, initially 660 volts, fell, passed through a minimum, and then rose. It is usual[5] for the starting potential to pass through a minimum if one begins with a pure noble gas and gradually adds a contaminant. The shape of the latter part of the curve is roughly that of a decaying exponential, but the relaxation time predicted, V/h+R, is only a third that observed. There is the same discrepancy in both experiments.

There is reason to believe that water vapor passing through the window, as well as air entering through leaks, can change the threshold of the counter.

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* Experiments by J. Brewer with the alpha hand counter[4] suggested this explanation. The permeability of Nylon to water vapor is many times its permeability to oxygen and nitrogen.[13]
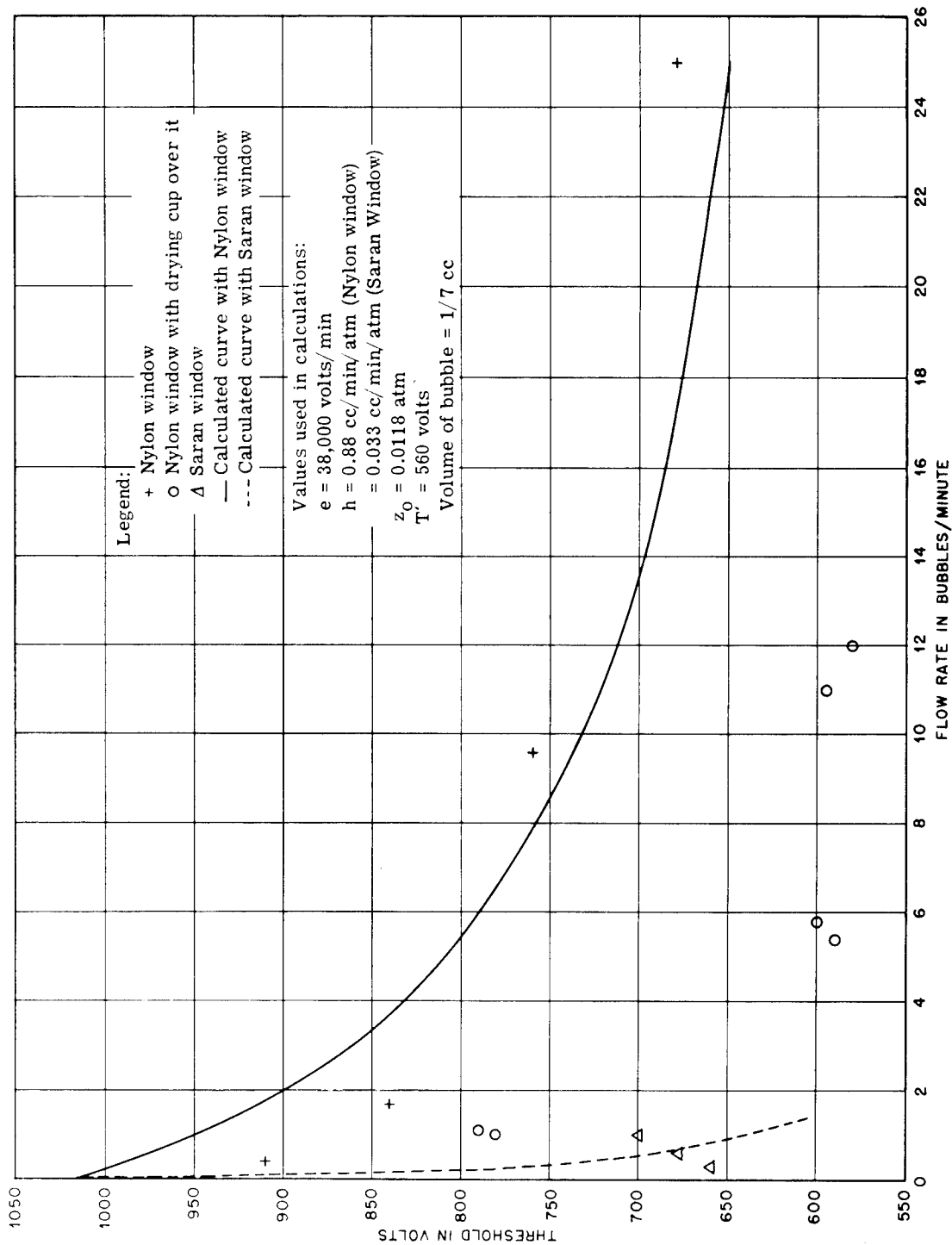
Figure 4. Threshold as function of flow rate under various conditions. Copper flow counter; flow system of metal and glass. 99.9% helium.

Figure 5a. Threshold as function of time. Copper flow counter with Nylon window; flow system of glass and metal. 99.9% helium. The system was evacuated and filled with helium. For twenty minutes the helium flowed rapidly through the system. Then the flow rate was reduced to 3 bubbles/minute and the first reading was taken.

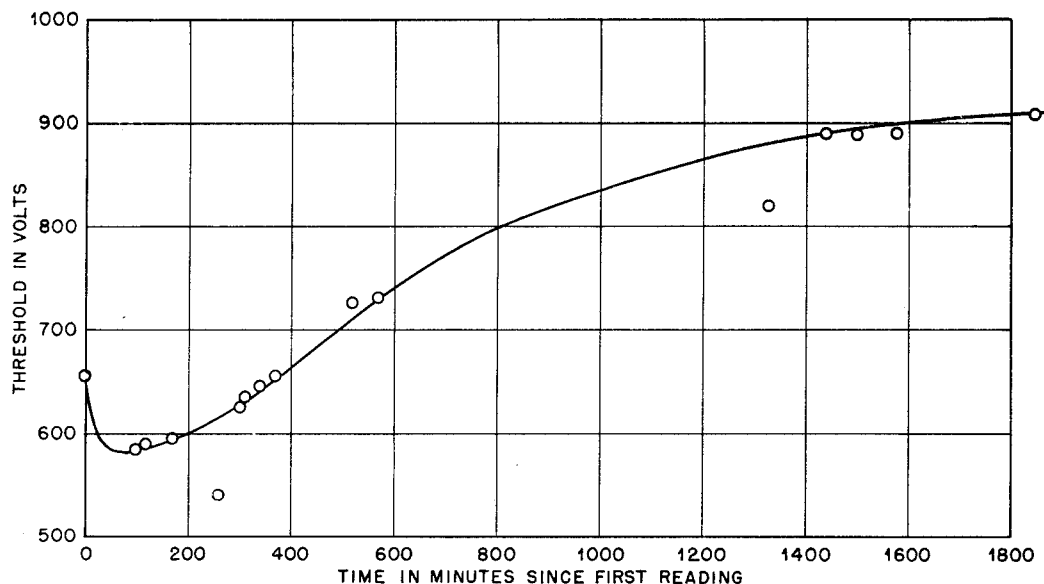Observed relation: $T = Ae^{-0.0014t} + B$ Predicted relation: $T = Ae^{-0.004t} + B$

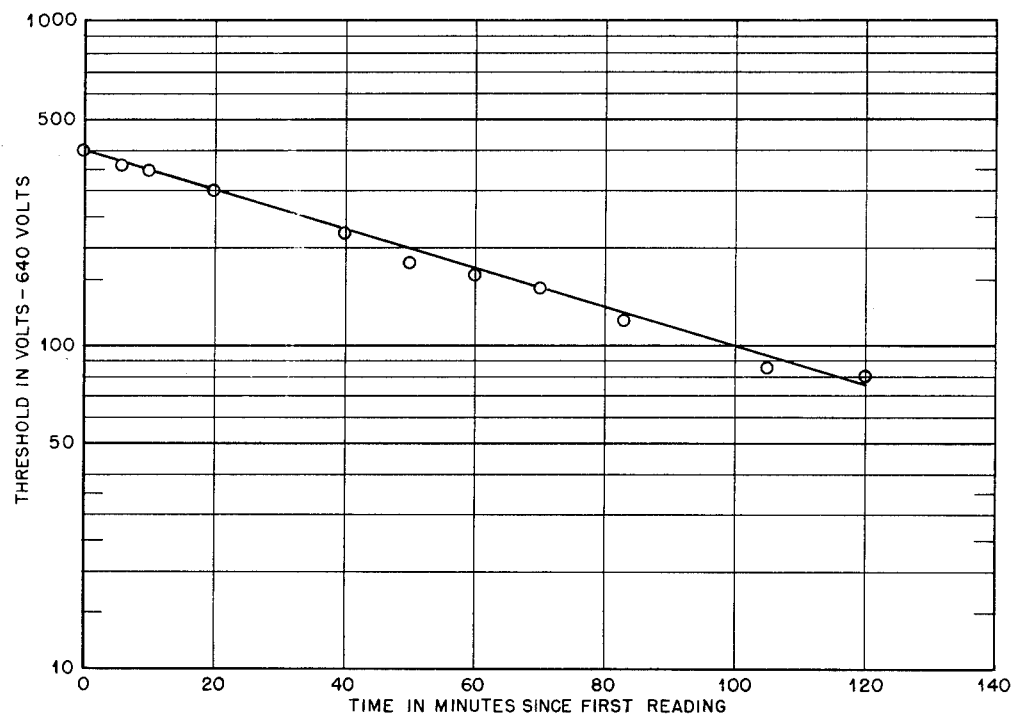Figure 5b. Threshold as function of time. Copper counter with Nylon window; flow system of glass and metal. 99.9% helium. The system was evacuated and filled with helium. Helium then flowed through the system at 3 bubbles/minute for five days. After increasing the flow to 85 bubbles/minute the observations began.

Observed relation: $T - 560 = 380e^{-0.013t}$ Predicted relation: $T - 560 = 380e^{-0.005t}$

Table 3. Permeability of various materials to water vapor.

Technical names of materials	Trade names	h (cc/min/atm)	Source of data*
Vinylidene chloride	Saran	0.033	6,7
Polyethylene		0.08	8
"Moistureproofed"	Cellophane	0.29	9
Polyamide	Nylon	0.78	6,10
Polystyrene		1.0	11
Aluminum paints		0.07-2	9
Cellulose nitrate	Celluloid	5.0	9
Ethyl cellulose		7.0	12
Cellulose acetate		5-50	9
Cellulose, regenerated	Cellophane	30	9

OTHER PROBLEMS

Table 3 contains data on the permeability of various materials to water vapor. The measurements[6] were made by putting calcium chloride in a test tube, sealing the film over the mouth of the tube, placing it in an atmosphere of known humidity, and weighing it every few days. (In such measurements the rate of transmission is not constant until the mass of H_2O which has passed through the film is several times the mass of H_2O absorbed in the film.) The value of h in the table is for a window with an area of 6 cm^2 and a mass per unit area of 4 mg/cm^2. In calculations it was assumed that the transmission rate varied directly as the area and the pressure difference, and inversely as the thickness. The permeabilities given are perhaps accurate within 30%.

Few if any of the plastic films are suitable for windows. The other possible materials are metal foils, plastics and metal combined, glass bubbles,[14] and mica. Metal foils often have pinholes. Mica has several advantages. On the other hand, if the atmosphere outside the window is dry, it does not matter that the window will transmit water vapor. If there is a shield[20] which has no large holes in it around the counter, one can either keep the shield full of a dry gas from a tank or use a desiccant to dry the air.

Sometimes, but not always, the air in the counter, during its manufacture, was evacuated before the helium was admitted. Two methods have been used to evacuate a counter without breaking the window. One, A, is to evacuate the counter under a bell jar,[15] fill it with helium, remove it from the bell jar, and attach it to the flow system. The other, B, is to place a cup over the window while evacuating.

To measure the flow rate, the helium discharged from the bubbler was collected over water. From this the approximate volume of a bubble was determined, and the flow rate in bubbles/min was translated into cc/min.

The impurities in the helium used were as follows (all concentrations being in mole percent):

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* References at the end of paper.

A   B
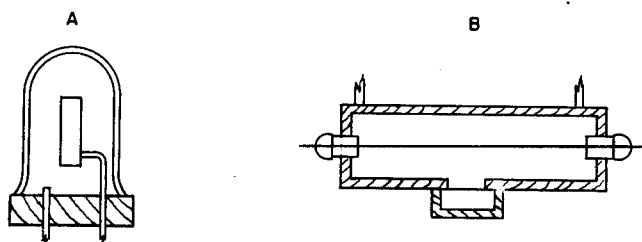
98% Helium[16]

Hydrogen	(0.10 0.02)	%
Nitrogen	(1.5 0.1)	%
Hydrocarbons	0.01	%

99.9% Helium[17]

Nitrogen	0.01	%
Hydrogen, oxygen, hydrocarbons	0.0005	%

Experiments by J. A. Simpson, S. C. Brown,[18] and C. L. Haines[19] agree that raising the pressure by one centimeter raises the threshold by five or ten volts.

SUMMARY

The threshold of a flow counter can change with the flow rate either because air diffuses into the counter through small leaks or because the window is porous to water vapor. Report CP 3613 continues the discussion of gas flow beta counters.

ACKNOWLEDGMENTS

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20. For details of shield see drawing No. MS10674. For details of counter, etc., see drawing No. MS10651.

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